Lake Michigan Shoreline TMDL for *E. coli* Bacteria

Sources Report

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1.0 Introduction

1.1 Purpose of Document

Indiana's portion of the Lake Michigan shoreline (Figure 1) encompasses 43 miles of the lake's total shoreline length (1,638 miles). It includes the Indiana Dunes National Lakeshore and many beaches that are used extensively by residents throughout the Midwest. The shoreline appears on Indiana's section 303(d) list of impaired waters for failing to fully support its swimmable designated use due to an *Escherichia coli* (*E. coli*) impairment (Table 1)[1]. The *E. coli* impairment was identified based on data collected by the Indiana Department of Environmental Management (IDEM) and the Inter-Agency Technical Task Force on *E. coli* (the Task Force) that showed violations of the water quality standard.

E. coli is a bacterium that indicates the presence of human sewage and animal manure. It can enter water bodies through direct discharge from mammals and birds, from agricultural and storm runoff carrying mammal wastes (manure), and from sewage leaked into the water. *E. coli* is also an indication of the possible presence of other disease causing organisms or pathogens. High bacteria levels closed National Lakeshore beaches 27 times in 2001 (Mitchell, 2003) with associated potential recreational and economic costs.

Table 1. Listing information for Lake Michigan from the Indiana 1998 section 303(d) list.

Waterbody	Designated Use	Support Status	Parameters of Concern
Lake Michigan	Aquatic Life Use	Full Support	--
	Swimmable	Partial Support	***E. coli***

Sources: IDEM, 1998a; IDEM, 1998b.

The Clean Water Act and U.S. Environmental Protection Agency (USEPA) regulations require that states develop Total Maximum Daily Loads (TMDLs) for all waters on the section 303(d) lists. A TMDL is the sum of the allowable amount of a single pollutant that a waterbody can receive from all contributing point and nonpoint sources and still support its designated uses. The overall goals and objectives of the Lake Michigan shoreline TMDL are to

- Assess the water quality of the Lake Michigan shoreline and identify key issues associated with the impairments and potential pollutant sources.
- Use the best available science to determine the maximum load of *E. coli* that the shoreline can receive and still fully support all of its designated uses.
- Use the best available science to determine current loads of *E. coli*.
- If current loads exceed the maximum allowable load, determine the load reduction that is needed.
- Identify feasible and cost-effective actions that can be taken to reduce loads.
- Inform and involve the public throughout the project to ensure that key concerns are addressed and the best available information is used.
- Submit a final TMDL report to USEPA for review and approval.

[1] Indiana's current section 303(d) list was submitted on April 15, 1998 and approved by USEPA in 1999. A draft 2002 section 303(d) list is currently being reviewed by USEPA.

A previous report described the physical setting of the Lake Michigan shoreline and discussed the spatial and temporal extent of *E. coli* levels (Tetra Tech, 2002). This Sources Report identifies and describes the nature, location, and magnitude of potential sources of *E. coli* bacteria. The following categories of sources are discussed:

- Tributary loads
- Stormwater runoff
- Septic systems
- Wildlife
- Other sources (e.g., boaters, swimmers)
- Boundary condition sources

Annual loads of *E. coli* from these sources are estimated using currently available information. As with all TMDLs a number of assumptions have had to be made due to a lack of complete information. IDEM is requesting feedback from readers regarding these assumptions so that they can be revised, if necessary, for use in the final TMDL. Once all comments have been received, the results of the source assessment will be used to setup and calibrate a water quality model that will simulate the effects of the *E. coli* loading on lake water quality. The final TMDL report will combine the results of all previous reports and address the regulatory requirements of the TMDL process.

Several stream segments located within the Lake Michigan basin also appear on Indiana's section 303(d) list and require TMDLs (Figure 1). However, this report focuses specifically on the shoreline and does not address the stream TMDLs. For example, upstream sources of *E. coli* that are transported to Lake Michigan through a tributary are not considered separately in this document (they are treated simply as tributary loads). The ongoing TMDLs being developed for Little Calumet River/Burns Ditch, Salt Creek, and Trail Creek will more fully quantify the source of loads (e.g., CSOs, septic systems, agriculture) to each major tributary.

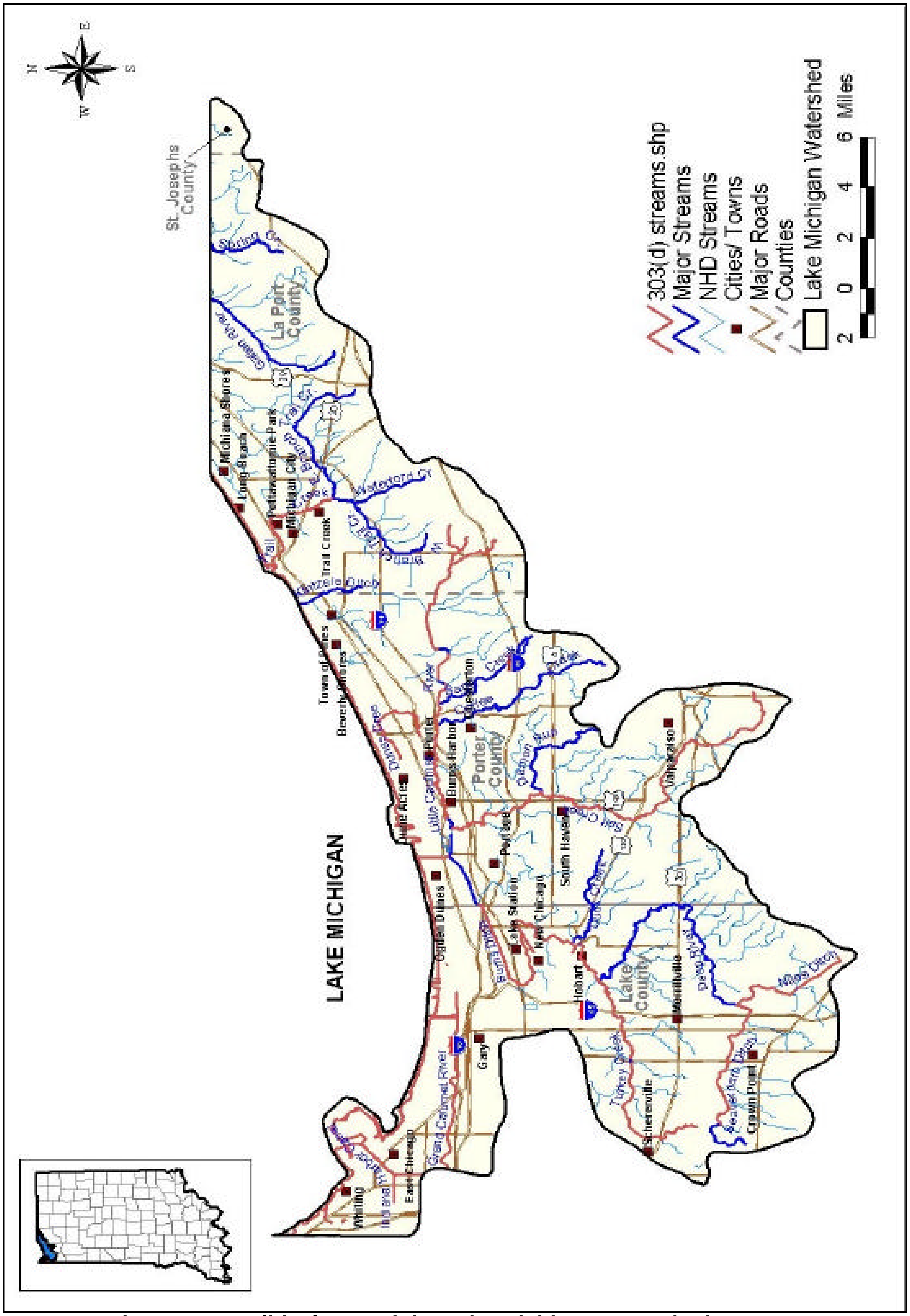


Figure 1. Political map of the Lake Michigan watershed.

1.2 Background

Pathogens are a serious concern for managers of water resources. Because of pathogens' small size, they are easily carried by storm water runoff or other discharges into natural waterbodies. Once in a stream, lake, or estuary they can infect humans through contaminated fish and shellfish, skin contact, or ingestion of water (USEPA, 2001). Excessive amounts of fecal bacteria in surface water used for recreation have been known to indicate an increased risk of illness to humans. Infection due to contaminated recreational waters include gastrointestinal, respiratory, eye, ear, nose, throat, and skin diseases (USEPA, 1986).

The numbers of pathogenic organisms present in polluted waters are generally few and difficult to identify and isolate, as well as highly varied in their characteristic or type. Therefore, scientists and public health officials typically choose to monitor nonpathogenic bacteria that are usually associated with pathogens transmitted by fecal contamination but are more easily sampled and measured. These associated bacteria are called indicator organisms. When large indicator organisms are present in the water, it is assumed that there is a greater likelihood that pathogens are present. Indicators are used to develop water quality criteria to support designated uses, such as primary contact recreation and drinking water supply.

All water bodies in Indiana are designated for recreational use. The numeric criteria associated with protecting the recreational use are described below.

> "This subsection establishes bacteriological quality for recreational uses. In addition to subsection (a), the criteria in this subsection are to be used to evaluate waters for full body contact recreational uses, to establish wastewater treatment requirements, and to establish effluent limits during the recreational season, which is defined as the months of April through October, inclusive. *E. Coli* bacteria, using membrane filter (MF) count, shall not exceed one hundred twenty-five (125) per one hundred (100) milliliters as a geometric mean based on not less than five (5) samples equally spaced over a thirty (30) day period nor exceed two hundred thirty-five (235) per one hundred (100) milliliters in any one (1) sample in a thirty (30) day period." [Source: Indiana Administrative Code Title 327 Water Pollution Control Board. Last Updated October 1, 2002]

The Lake Michigan Data Report (Tetra Tech, 2002) presents the available *E. coli* data at the Lake Michigan shoreline and compares them to the water quality standard. The discussion below presents an analysis of the likely sources of *E. coli* to the shoreline.

2.0 Point Sources

The term point source refers to any discernible, confined, and discrete conveyance, such as a pipe, ditch, channel, tunnel or conduit, by which pollutants are transported to a waterbody. It also includes vessels or other floating craft from which pollutants are or may be discharged. By law, storm water runoff from certain areas is also considered a point source because the water is transported through a pipe or ditch (see discussion below on Phase II communities).

Estimating the transport of *E. coli* into a surface waterbody from some point sources is a fairly straightforward matter. For example, wastewater treatment plants (WWTP) discharge though a constructed conveyance and can be easily monitored. It is much more difficult to quantify the loadings of *E. coli* from other point sources, such as storm water runoff.

2.1 Wastewater Treatment Plants

Treated municipal sewage is a point source of bacterial contamination. Not all human pathogens are removed or rendered harmless by treatment processes. Raw sewage entering the WWTP typically has a total coliform count of 10,000,000 to 1,000,000,000 (1E+7 to 1E+9[2]) counts per 100 mL) (Novotny et al., 1989). Associated with raw sewage are proportionally high counts of pathogenic bacteria, viruses and protozoans. A typical wastewater treatment plant reduces the total coliform count by about three orders of magnitude. The magnitude of reduction, however, varies with the treatment process employed.

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. There are several facilities regulated by the NPDES program within the Lake Michigan watershed that discharge *E. coli*. However, none of these discharge directly into the lake.

2.2 Combined Sewer Overflows

Combined sewer systems are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Most of the time, combined sewer systems transport all of their wastewater to a sewage treatment plant where it is treated and then discharged to a waterbody. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other waterbodies. These overflows, called combined sewer overflows (CSOs), contain not only storm water but also untreated human and industrial waste, toxic materials, and debris. Because they are associated with wet weather events, CSOs typically discharge for short periods of time at random intervals.

Although there are numerous CSOs in the Lake Michigan watershed, none discharge directly to the shoreline. The CSO contribution to the Lake Michigan tributary loads is therefore being investigated as part of the TMDLs developed for the Little Calumet River/Burns Ditch, Salt Creek, and Trail Creek.

[2] Because the counts of *E. coli* can be so large, scientific notation is typically used to express them. Scientific notation is a method scientists have developed to express very large numbers. Scientific notation is based on powers of the base number 10. The number 10,000,000 is written as 1×10^7 or 1E+7.

2.3 Storm Water Phase II Communities

Storm water runoff can contribute *E. coli* bacteria and other pollutants to a waterbody. Material can collect on streets, rooftops, parking lots, sidewalks, yards and parks and then during a precipitation event this material can be flushed into gutters, drains, and culverts and be discharged into a waterbody.

The U.S. EPA developed rules in 1990 that established Phase I of the NPDES storm water program. The purpose of this program is to prevent harmful pollutants from being washed by storm water runoff into Municipal Separate Storm Sewer Systems (MS4s) (or from being dumped directly into the MS4) and then discharged into local waterbodies. Phase I of the program required operators of medium and large MS4s (those generally serving populations of 100,000 or greater) to implement a storm water management program as a means to control polluted discharges from MS4s. Only the City of Indianapolis met Phase I criteria within the State of Indiana.

Under Phase II, rules have been developed to regulate most MS4 entities (cities, towns, universities, colleges, correctional facilities, hospitals, conservancy districts, homeowner's associations and military bases) located within mapped urbanized areas, as delineated by the U.S. Census Bureau, or, for those MS4 areas outside of urbanized areas, serving an urban population greater than 7,000 people. The following entities along the Lake Michigan shoreline fall under the Phase II guidelines:

- Burns Harbor
- East Chicago
- Gary
- Lake County
- LaPorte County
- Long Beach
- Michigan City
- Ogden Dunes
- Portage
- Porter County
- Whiting

Operators of Phase II-designated small MS4s are required to apply for NPDES permit coverage and to implement storm water discharge management controls (known as “best management practices” (BMPs)).

Loads of *E. coli* from most of the urban storm water sources along the Lake Michigan shoreline are included in the estimates of tributary loads below. Direct discharge of storm water from these communities directly into the lake is not considered a significant source of *E. coli*.

3.0 Nonpoint Sources

Nonpoint sources of pathogens are much more difficult to identify and quantify than are point sources. In urban areas, nonpoint sources can include leaking or faulty septic systems, pet waste, storm water runoff (outside of Phase II communities), and other sources. In more rural areas, major contributors can be pasture land runoff, manure storage and spreading, concentrated animal feedlots, and wildlife. Potentially significant nonpoint sources of pathogens to the Lake Michigan shoreline include tributary loadings, septic systems, wildlife, and other sources such as swimmers and boaters. Each of these sources is discussed below.

It is important to note that this document only focuses on those nonpoint sources that discharge directly to Lake Michigan. For example, upstream sources of *E. coli* that are transported to Lake Michigan through a tributary are not considered separately in this document (they are included with the tributary loads). The ongoing TMDLs being developed for Little Calumet River/Burns Ditch, Salt Creek, and Trail Creek will more fully quantify the source of loads to each major tributary.

3.1 Tributaries

Tributaries that enter Lake Michigan within Indiana include Burns Ditch, the Indiana Harbor Ship Canal, Trail Creek, and several smaller tributaries and man-made ditches. Together these tributaries are considered the most significant source of pathogens to the shoreline.

The present hydrology of the Lake Michigan shoreline is significantly altered from what existed before industrial development began in the late nineteenth century. Figure 2 presents a map of the major tributaries in their present day configuration. A brief description of the area and important hydrologic issues follows.

Beginning from the northwest, the first tributary discharging to Lake Michigan within the Little Calumet-Galien Hydrologic Cataloguing Unit (04040001) is the Calumet River which discharges to the Calumet Harbor in Illinois. Continuing eastwards, an artificial channel connects Lake Michigan to Wolf Lake. However, water flows from Lake Michigan into Wolf Lake and therefore this channel is not considered a significant source of pathogens to the shoreline.

The area to the east of the Wolf Lake channel, from the Indiana Harbor Ship Canal to the Indiana Dunes National Lakeshore, is one of the oldest industrial corridors in the country. The watershed that drains this area has undergone significant hydrologic modification, including an alteration to the natural flow and course of the Grand Calumet and Little Calumet Rivers. These two rivers were once a single waterway that began in LaPorte County and flowed west though Porter and Lake Counties into Illinois. In Illinois the river flowed toward the northwest, curved to the northeast, re-entered Lake County and finally emptied into Lake Michigan at what is now Marquette Park in Gary (IDNR, 1996). The East Branch of the Grand Calumet River now flows westwards with its present outlet at the Indiana Harbor and Ship Canal. The West Branch of the Grand Calumet River usually flows both west and east, with a hydraulic divide typically present in the vicinity of Indianapolis Boulevard (USACE, 2001).

The Indiana Harbor and Ship Canal was constructed in the 1900s to serve the shipping needs of the steel industries and oil refineries in the area. The canal has a 'Y' shape with the Lake George Branch running east/west, the Indiana Harbor Branch, which links to the Grand Calumet, running north/south, and the United States Branch running southwest to northeast into Lake Michigan at the Indiana Harbor. The eastern half of the West Branch of the Little Calumet River flows eastwards and empties into Lake Michigan through Burns Ditch, a man-made channel constructed in 1926.

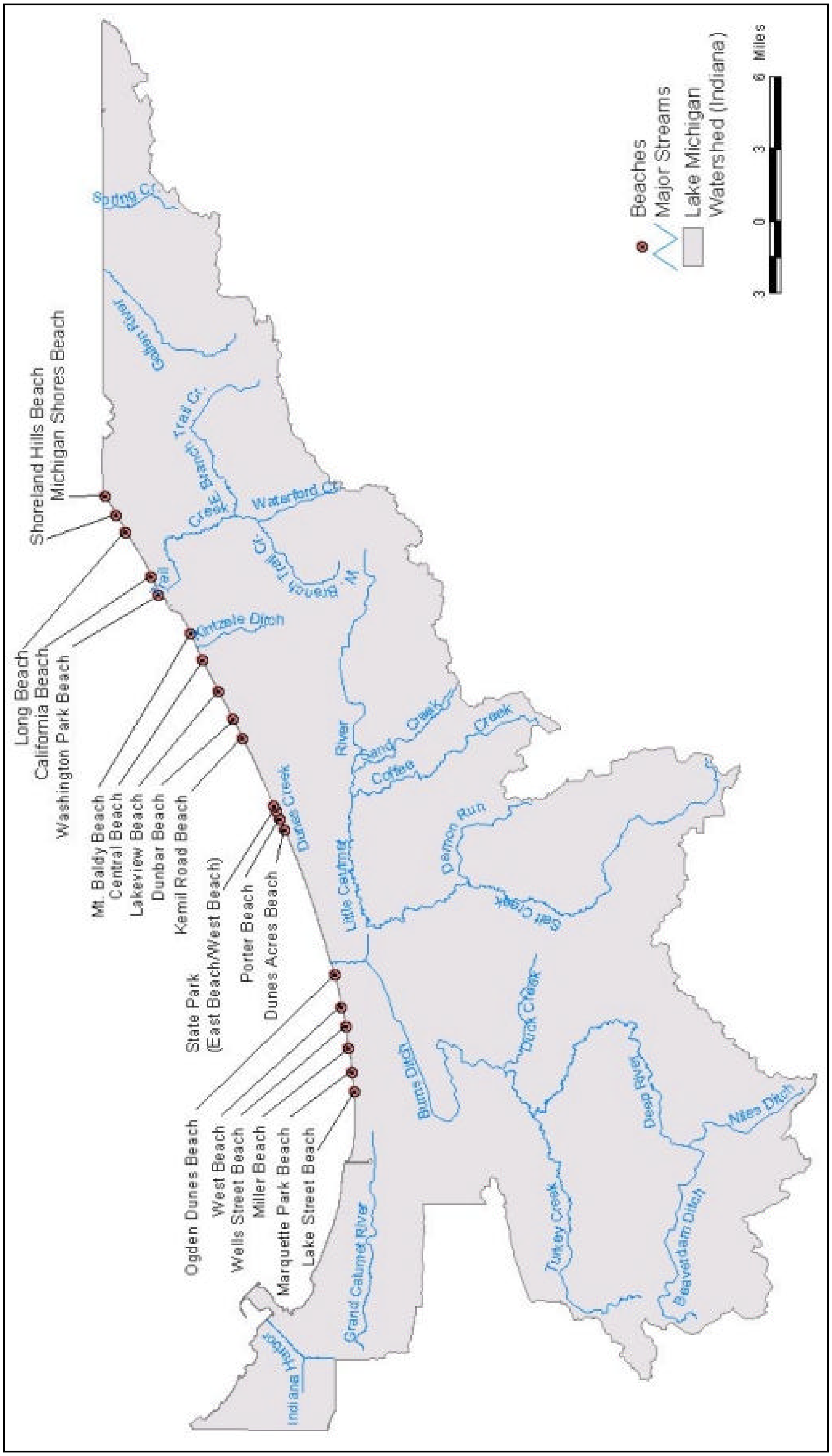


Figure 2. Tributaries to Lake Michigan within Indiana.

The Indiana Dunes National Lakeshore runs for nearly 25 miles along southern Lake Michigan, bordered by Gary on the west and Michigan City on the east. The Lakeshore is characterized by sand hills that were formed over many years due to fluctuating lake levels. Several small tributaries flow through the Lakeshore, including Dunes Creek, Derby Ditch, and Kintzele Ditch. The last significant tributary to Lake Michigan within Indiana is Trail Creek, which flows through Michigan City near the Indiana and Michigan border and has its outlet in the Michigan City Harbor.

Existing streamflow and water quality data were used to make estimates of the load of *E. coli* from each of the significant Indiana tributaries to the Lake Michigan shoreline. Table 2 identifies the tributaries that discharge to the Indiana shoreline along with the available streamflow and water quality sampling stations. For stations with available streamflow and *E. coli* counts, loads have been calculated using the following formula:

$$\text{Average Daily Load (count/day)} = \frac{\text{Flow (cfs)} \times \text{E. coli (count/100 mL)} \times 86400\ \text{(sec/day)} \times \text{Conversion Factor}}{\text{\# of days sampled}}$$

For stations lacking overlapping *E. coli* and streamflow data, estimation methods were applied to produce a realistic loading scenario. The details of such methods and the results of the loading calculations are discussed in the subsequent sections.

Table 2. Summary of data used to estimate tributary loads of *E. coli* to the Lake Michigan shoreline.

Tributary Name	Drainage Area (square miles)	Flow Gage	Water Quality Station(s)	Description
Burns Ditch	331	USGS 04095090	LMG060-0006	Midwest Steel Catwalk, Portage
			Task Force Station 225	Burns Harbor at Mouth
Derby Ditch	9.6	USGS 04095100	Task Force Station 301	Derby Ditch at Mouth
Dunes Creek	3.4	USGS 04095050	Task Force Station 302	Dunes Creek at Mouth
Indiana Harbor Ship Canal (IHSC)	37.0	USGS 04092750	Task Force Station 111	IHSC at mouth
			Task Force Station 110	IHSC at Dickey Rd
			LMG020-0003	Bridge on Dickey Rd
Kintzele Ditch	9.5	Not available	LMG080-0001	Beverly Shores Rd
			Task Force Station 308	Kintzele Ditch at Mouth
Trail Creek	59.1	USGS 04095380	Task Force Station 409	Trail Creek at Michigan City Harbor

3.1.1 Burns Ditch

Burns Ditch, also known as the Portage Burns Waterway, is a man-made channel constructed in 1926. The Burns Ditch/Little Calumet River watershed drains approximately 331 square miles in and is the second largest inflow to Lake Michigan on the Indiana shoreline. It drains an urbanized and agricultural watershed that includes several sources of *E. coli*, including storm water runoff, WWTPs, SSOs, CSOs, septic systems, livestock, and wildlife.

Streamflow at the mouth of Burns Ditch has been continuously monitored by the U.S. Geological Survey (USGS) near its outlet (USGS 04095090). The waterway discharged an average of 290 million gallons per day to Lake Michigan for the period 1997 to 2001. Water quality is monitored at various nearby locations by IDEM and the Task Force with stations at the Midwest Steel Catwalk in Portage (IDEM Station LMG060-0006) and at Burns Harbor (Task Force Station 225).

Aerial photograph showing a discharge plume from Burns Ditch flowing into Lake Michigan. (Photo by Indiana University and Indiana Geological Survey.)

Figure 3 presents the available water quality for Burns Harbor and the corresponding streamflow for Burns Ditch at the USGS gage. A statistical analysis of correlation indicated that flow and *E. coli* counts are highly correlated (P-value < 0.0001). These results indicate that sources of *E. coli* are associated with wet weather discharges and are similar to those reported by other researchers (Olyphant, 2003).

Using the available Burns Ditch water quality and flow data for the 1998 to 2001 time period an average daily load to Lake Michigan was calculated at 9.51E+12 counts/day for the April to October sampling season. Peaks loads were as high as 3.54E+14 counts/day during wet weather events when both streamflow and *E. coli* counts were elevated.

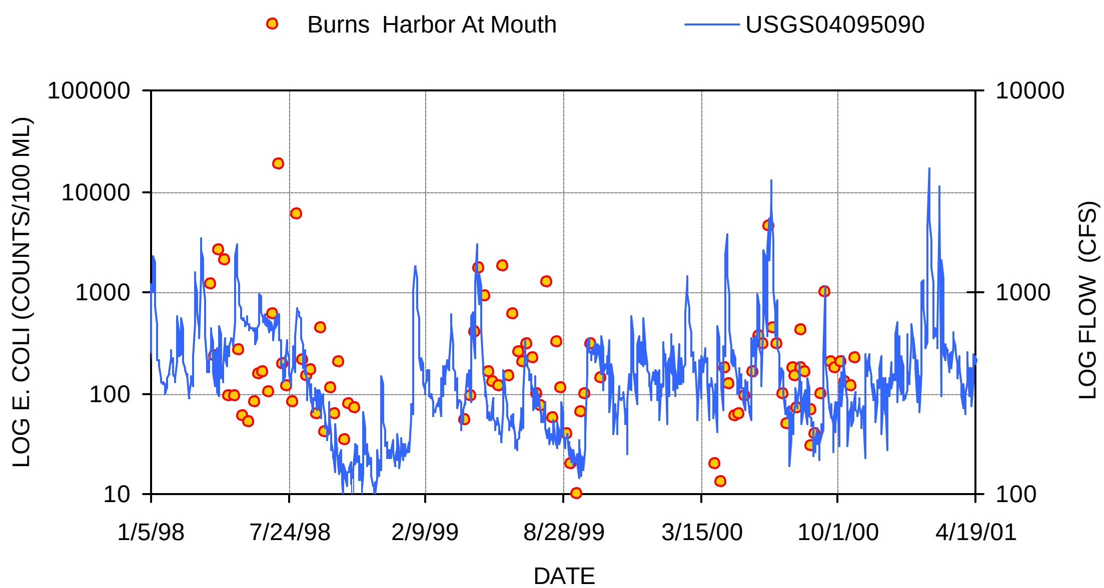


Figure 3. Water quality and streamflow data for Burns Harbor.

To evaluate the effect of loads from Burns Ditch on Lake Michigan water quality, the data for Burns Ditch were compared to the data at West Beach (which is located west of Burns Harbor). Figure 4 presents the comparative fluctuations of *E. coli* counts over time for these two stations. A statistical analysis of correlation showed that these two time series are highly correlated.

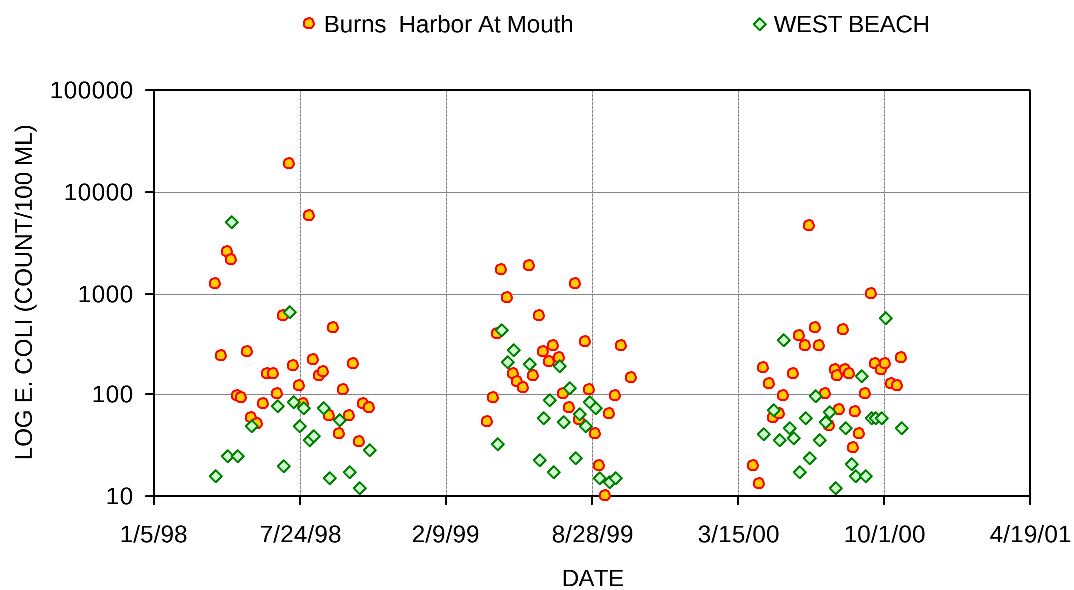


Figure 4. Comparison of Burns Harbor and West Beach *E. coli* data.

3.1.2 Derby Ditch

Derby Ditch flows through the Indiana Dunes National Lakeshore up to Beverly Shores and drains a small watershed approximately 9.6 square miles in area. USGS monitored flow in Derby Ditch from 1978 to 1982 (USGS 04095100) and Indiana University, USGS, and the Indiana Geological Survey monitored flow from 1997 to 2000 (Olyphant et al., 2003). The drainage area of Derby Ditch includes wetlands and limited residential development. Sources of *E. coli* are likely to include primarily wildlife (e.g., deer, raccoons, ducks, and geese). Water quality data are available for the period 1998 to 2002 at Task Force Station 301.

Derby Ditch discharging to Lake Michigan (Photo by Tetra Tech, Inc.)

Monitoring at Derby Ditch from 1997 to 2000 indicated that *E. coli* counts increase during storms with the highest counts generally occurring during rising streamflow. Multiple regression analysis indicated that 60 percent of the variability in measured outflows of *E. coli* could be accounted for by a statistical model that utilizes continuously measured rainfall, stream discharge, soil temperature, and depth to water table in the Great Marsh (Olyphant et al., 2003).

Since the 1997 to 2000 streamflow data for Derby Ditch have not yet been obtained for this study, loads were estimated by forecasting flow during the period 1998 to 2001 using a forecasting model developed with flow and rain data for the gaged time period. These flows were then used with the observed *E. coli* data to generate daily loading estimates. The results indicate that loads of *E. coli* from Derby Ditch to Lake Michigan average 4.52E+10 counts/day for the April to October time period. These estimates will be updated once the 1997 to 2000 streamflow data are obtained but are not expected to change significantly.

3.1.3 Dunes Creek

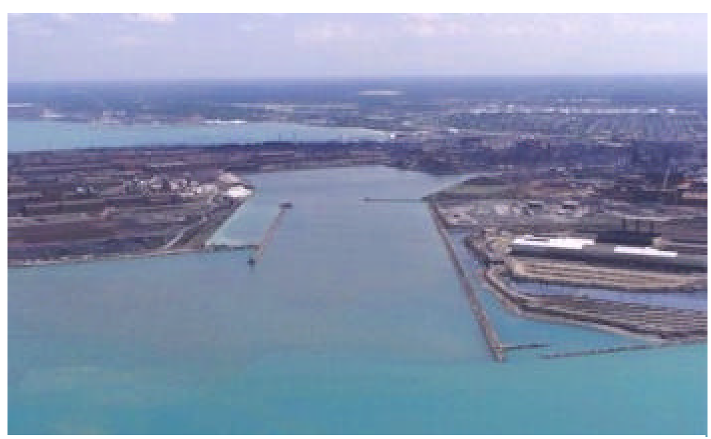
Dunes Creek also flows through the Indiana Dunes National Lakeshore and its watershed is 3.41 square miles in area. Sources of *E. coli* are likely to include primarily wildlife (e.g., deer, raccoons, ducks, and geese). Dunes Creek streamflow was monitored at the confluence with Lake Michigan near Dune Acres from 1978 to 1982 (USGS 04095050). Water quality has been monitored at the shoreline (Task Force Station 302) and at Dune Acres Beach (Task Force Station 303) from 1998 to 2002.

Dunes Creek discharging to Lake Michigan. (Photo by Tetra Tech, Inc.)

Since the time periods for *E. coli* counts and flow do not coincide, loads were estimated by forecasting flow during the period 1998 to 2002 using a forecasting model developed with flow and rain data for the gaged time period. These flows were then used with the observed *E. coli* data to generate daily loading estimates. The results indicate that loads of *E. coli* from Dunes Creek to Lake Michigan average 8.38E+10 counts/day for the April to October time period.

3.1.4 Indiana Harbor Ship Canal

The Indiana Harbor Ship Canal (IHSC) is located in the northwest corner of Indiana within the cities of East Chicago and Hammond. The canal was built to service the industrial corridor between the Grand Calumet River and Lake Michigan and it drains approximately 37 square miles of a mostly industrialized watershed. Streamflow has been monitored continuously since 1991 at a gage less than two miles away from Lake Michigan. The average flow is approximately 400 million gallons per day. Water quality is monitored at several stations, including one at the outlet with Lake Michigan (Task Force Station 111), and two at Dickey Road, 1.2 miles upstream from the shore (Task Force Station 110 and LMG020-0003). Representative *E. coli* counts for the IHSC



Indiana Harbor Ship Canal (Photo by U.S. Army Corp of Engineers)

were made by averaging the data at Dickey Road with the data in the harbor. This was done to account for dilution that occurs due to a large volume of industrial cooling water that is discharged between the two points.

Figure 5 presents the available water quality and streamflow data for the IHSC. There does not appear to be any clear relationship between flows and *E. coli* counts. This indicates that there are likely both wet weather and constant discharge sources of *E. coli* in the drainage area. Using the available water quality and flow an average load was estimated at 1.04E+13 counts/day for the April to October time period. Peak loads were as high as 5.33E+14 counts/day.

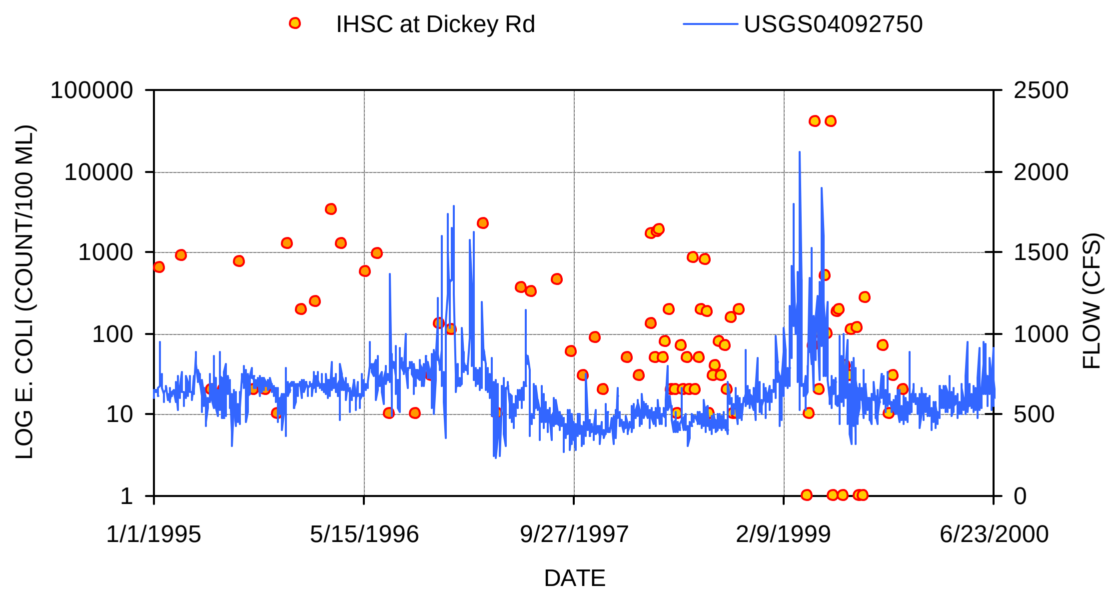


Figure 5. Streamflow and water quality data for the Indiana Harbor Shipping Canal.

3.1.5 Kintzele Ditch

Kintzele Ditch also flows through the Indiana Dunes National Lakeshore and its watershed is 9.5 square miles in size. No continuous streamflow data for Kintzele Ditch are known to be available. Therefore an area weighted estimate of flow was made using streamflow data from neighboring gages. These flow estimates, in combination with the *E. coli* data available from Task Force Station 308, result in an estimated daily load of 6.68E+10 counts/day from Kintzele Ditch.

3.1.6 Trail Creek

Trail Creek flows into Lake Michigan and has a drainage area of approximately 59 square miles. The USGS gage on Trail Creek, active since October of 1994, is located at river mile 0.5 at the Franklin Street drawbridge in Michigan City. Water quality is monitored at the Michigan City Harbor (Task Force Station 409) at the outlet of Trail Creek to Lake Michigan (Station LMG070-0007).

Figure 6 presents the available water quality and streamflow data for Trail Creek. Using the available water quality data and flow data from 1998 to 2001 an average load was estimated at 3.11E+12 counts/day for the April to October time period. Peak loads are as high as 1.07E+14 during wet weather events.

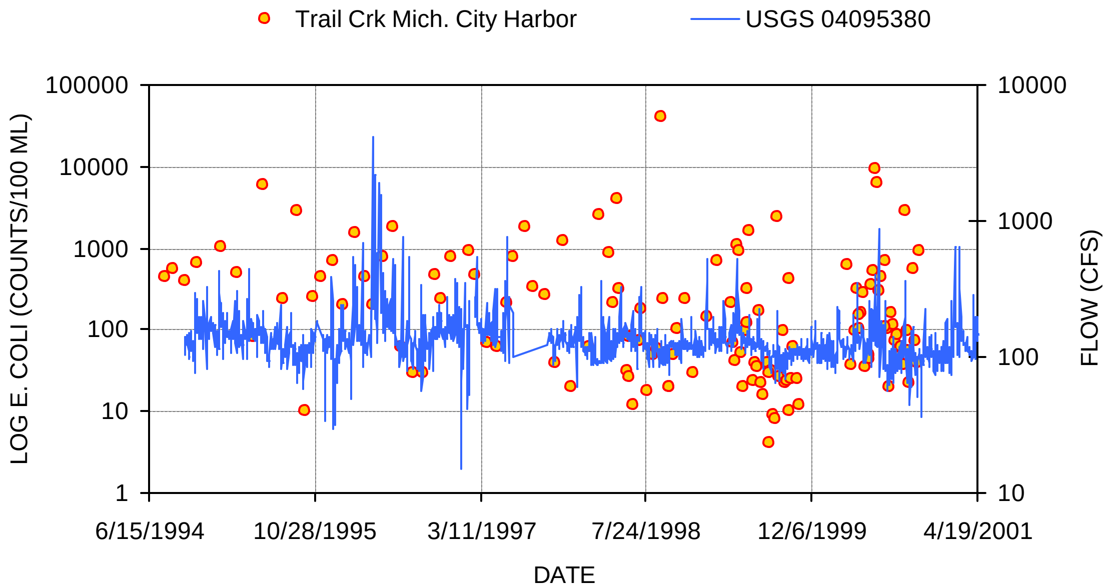


Figure 6. Water quality and streamflow data for Trail Creek.

To evaluate the effect of loads from Trail Creek on Lake Michigan water quality, the data for Trail Creek were compared to the data at Washington Park Beach (which is located near Michigan City Harbor). Figure 7 presents the comparative fluctuations of *E. coli* counts over time for these two stations. A statistical analysis of correlation showed that these two time series are correlated.

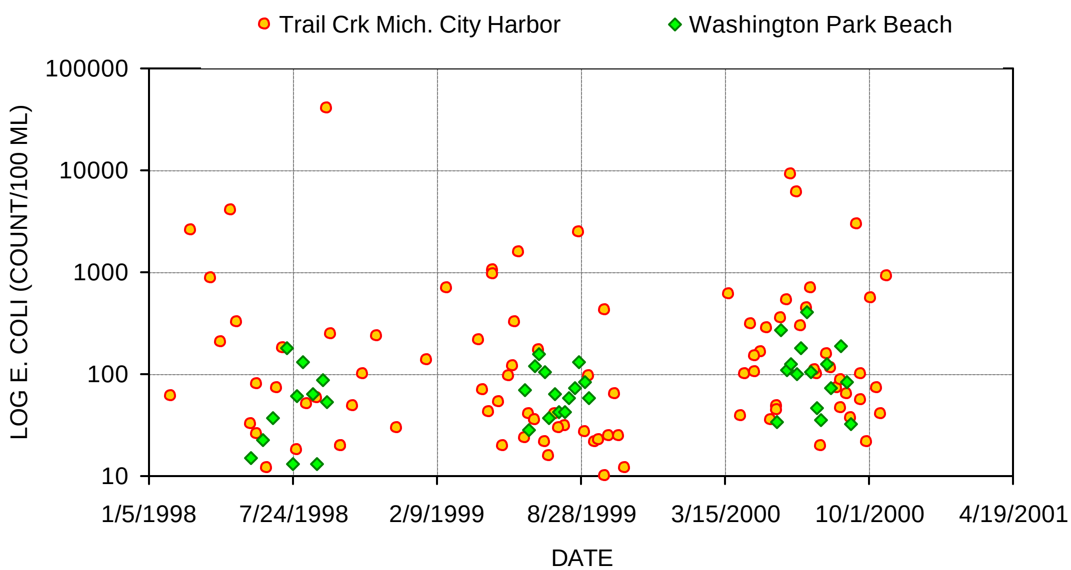


Figure 7. Comparison between Trail Creek and Washington Park Beach *E. coli* data.

3.2 Septic Systems

Septic systems that are properly designed and maintained should not serve as a source of contamination to surface waters. However, septic systems do fail for a variety of reasons. Common limitations that contribute to failure include poor soil conditions, inadequate maintenance, and illicit connections. When septic systems fail hydraulically (surface breakouts) or hydrogeologically (inadequate soil filtration) there can be adverse effects to surface waters down gradient (Horsely and Witten, 1996).

Site-specific information on the location of failing or illicitly connected septic systems is not currently available for the Lake Michigan watershed. Therefore estimates of the loads of *E. coli* from these sources must be based on the assumptions outlined below:

- Number of persons served by septic systems potentially discharging directly into Lake Michigan is defined as those living in houses within 500 feet of the shoreline. The number of houses on septic systems was derived from 1990 and 2000 US Census and an analysis performed using a geographic information system (Figure 8).
- An average daily discharge of 70 gallons/person/day (Horsley and Witten, 1996)
- Septic effluent *E. coli* concentration of 1,000,000 counts/100 ml (Powelson and Mills, 2001)
- Average septic failure rate for each location of 5 to 10 percent (best professional judgment).

Table 3 presents the *E. coli* bacteria loading from septic systems calculated using the above information. The loads are presented by city or town. Cumulatively, septic systems represent a potential load of *E. coli* to the shoreline of 2.08E+11 counts/day.

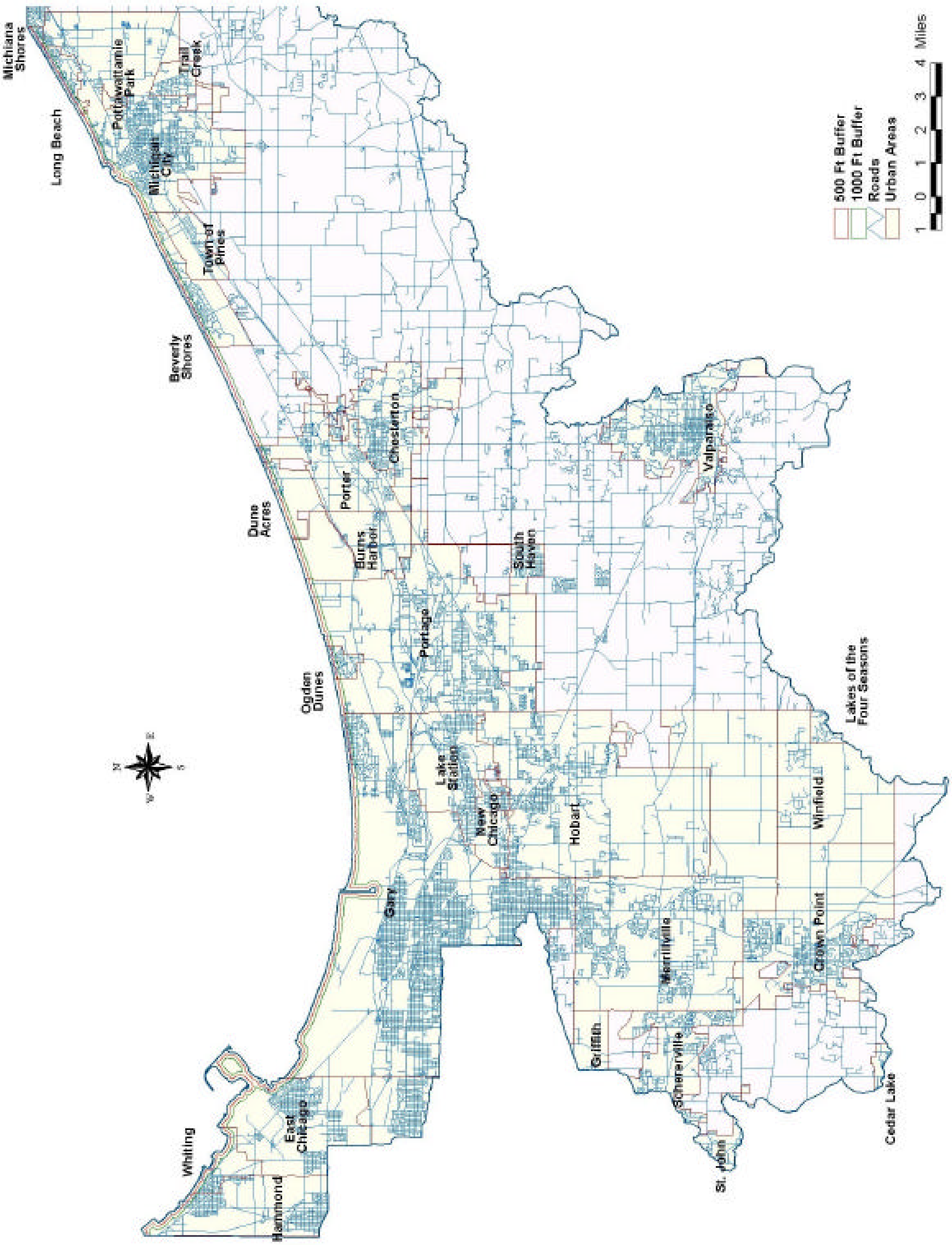


Figure 8. Distribution of urban areas along the Lake Michigan shoreline.

Table 3. Estimated loading from septic systems along the Lake Michigan shoreline.

Location	Total Population (2000 Census)	Proportion of Population on Septic Systems (1990 Census)	Proportion of Population within 500 feet of shoreline (GIS analysis)	Total Population Served by Septic Systems within 500 feet of shoreline	Proportion Failing	Estimated Daily E. coli Load (count/day)
Beverly Shores	708	75%	3%	16	5%[A]	2.10E+09
Burns Harbor	766	82%	1%	6	10%	1.66E+09
Dune Acres	213	98%	1%	2	10%	5.51E+08
East Chicago	32414	<1%	1%	1	10%	1.54E+08
Long Beach	1559	86%	11%	148	10%	3.91E+10
Michiana Shores	330	96%	18%	57	10%	1.52E+10
Michigan City	32900	7%	0%	1	10%	3.54E+08
Ogden Dunes	1313	95%	30%	376	10%	9.96E+10
Portage	33496	8%	1%	26	10%	6.89E+09
Pottawattomi Park	300	82%	5%	12	10%	3.26E+09
Town of Pines	798	97%	5%	39	10%	1.02E+10
Trail Creek	2296	94%	5%	108	10%	2.87E+10
Whiting City	5137	<1%	15%	2	10%	6.17E+08
				794		2.08E+11

[A] A previous study concluded that contamination of the Indiana Dunes water-table aquifer by Beverly Shores drywells is minimal when the sand is not saturated (Olyphant and Harper, 1995).

3.3 Wildlife

Various species of wildlife have been identified as potentially significant sources of *E. coli* to the Lake Michigan shoreline. These include deer, raccoons, ducks, geese, and seagulls (Olyphant et al., 2003; Whitman et al., 2001). One method to differentiate between human and non-human sources of bacteria is to use DNA fingerprinting of the *E. coli* bacteria present in the waterbody, and match the results with a library of *E. coli* strands. This allows an estimation of the amount of pollution coming from which species. However, this methodology is not an available resource to this TMDL because it is costly and requires the development of a location-specific DNA library. Another method is to estimate the wildlife population and the amount of *E. coli* that each organism may contribute and compare those results to loads estimated from other sources. That is the approach taken by this study using the following equation:

$$\text{Average Load (count/day)} = \text{Number of Animals} \times \text{E.coli Generation Rate (count/day)} \times \text{Portion of Day at Shore}$$

Raccoons are found throughout Indiana. They are most numerous where a good mixture of woodlands, cropland, and shallow water are found. Under ideal conditions, raccoon levels can approach one per acre.

Even in less favorable habitat, they still may occur at the rate of about one raccoon per 40 acres. The total number of raccoons in the Lake Michigan shoreline was conservatively estimated by multiplying the total number of forested, wetland, residential, and agricultural acres within 1000 feet of the shoreline (1700 acres) by one raccoon per acre. Raccoons were assumed to generate 1.6E+8 counts/day of *E. coli* (ASAE, 1998) and spend approximately 10 percent of each day at or near the shoreline. These assumptions resulted in an estimated load of *E. coli* from raccoons at 2.72E+10 counts/day.

The white-tailed deer are Indiana's sole representative of the family Cervidae, which includes mule deer, elk and moose. White-tailed deer occupy both forest and non-forest habitat types throughout Indiana. Population estimates are available from the Indiana Department of Natural Resources (IDNR, 2003) and indicate that there are approximately 0.02 deer per acre. The total number of deer in the Lake Michigan shoreline was estimated by multiplying the total number of forested, wetland, residential, and agricultural acres within 1000 feet of the shoreline by 0.02 deer per acre. The deer were assumed to generate 4.3E+9 counts/day of *E. coli* (ASAE, 1998) and spend approximately 10 percent of each day at or near the shoreline. These assumptions resulted in an estimated load of *E. coli* from deer of 1.47E+10 counts/day.

Seagulls are another potential source of *E. coli* to the Lake Michigan shoreline especially because, unlike deer and raccoons, they spend the majority of their time on the beach or in the nearshore waters. Whitman et al. (2001) conducted a comprehensive study of *E. coli* conditions at 63rd Street Beach in Chicago and identified seagulls as among the largest contributors. The number of seagulls was found to be lowest in April and May and peaked in June, July, and August. There was no significant difference between morning and afternoon bird populations when the entire season was inspected. The average number of gulls for the entire season was approximately 500 per mile.

Estimates of the number of seagulls on the Indiana portion of the Lake Michigan shoreline during the summer were made using the data reported by Whitman et al. (2001) and a generation rate of 5.4E+8 counts/day of *E. coli* (Roll and Fujioka, 1997). The seagulls were assumed to spend 75 percent of the time at or near the shoreline. These assumptions resulted in an estimated load of *E. coli* from seagulls of 5.37E+12.

3.4 Boaters and Swimmers

Swimmers have been mentioned as potential sources of *E. coli* to the shoreline. Information from the Indiana Dunes National Lakeshore indicates that approximately 10,500 persons visit the Lakeshore beaches on an average day during the summer (June, July, and August). Assuming that one out of every four of these visitors use the Lakeshore's restroom facilities and assuming that 10 percent of this waste reaches the shoreline results in an estimated load from swimmers of 6.9E+11.

Boaters have also been mentioned as a potential source of *E. coli* even though the discharge of untreated sewage from any vessel in Lake Michigan or a navigable tributary is generally prohibited by federal and state law. Little information is available upon which to estimate the load of *E. coli* from illegal boat discharges. The load has been roughly estimated by assuming it is 50 percent of that from swimmers.

4.0 Conclusions

Figure 9 summarizes the results of the source loading analysis for the Indiana portion of the Lake Michigan shoreline. Loads from the Indiana Harbor Ship Canal, Burns Ditch, seagulls, and Trail Creek are shown to be the most significant sources. Loads from boaters, swimmers, and septic systems are of secondary importance and loads from the smaller tributaries and other wildlife are not significant compared to the other loads

A number of assumptions, documented throughout this report, have been made in deriving the results shown in Figure 9. Loads from the major tributaries are known with the most certainty because they are based on observed streamflow and *E. coli* data but the loads from other sources rest on a number of key assumptions. A sensitivity analysis was conducted to determine the extent to which the results significantly change based on these assumptions:

- No flow data are available for Kintzele Ditch. If actual flows are twice what was estimated using the area-weighted approach the load from Kintzele Ditch is still less than 1 percent of the total.
- No data are available on the proportion of the septic systems located along the shoreline that might be failing. If 80 percent (instead of 10 percent) of the systems are failing the load to the shoreline from septic systems increases from 1 percent of the total load to 4 percent.
- Few data are available on the number of seagulls that might be located on the shoreline during a typical summer day. The data from the 63rd Street Beach study might overestimate conditions for the entire Indiana shoreline. If the number of seagulls is one-half of what was used the load from seagulls drops from 18 percent of the total load to 10 percent.
- No data are available on the length of time deer and raccoon might spend at the shoreline. If they spend 40 percent of their time (instead of 10 percent) their load is still less than 2 percent of the total load.

These considerations confirm the conclusion that the most significant sources of *E. coli* appear to be the major tributaries and seagulls. Cumulatively these sources account for 95 percent of the estimated load. The conclusion that seagulls are a potentially significant source of *E. coli* is similar to that reached by a previous study (Whitman et al., 2001).

It is important to note that the results of Figure 9 only address the waste generation and potential transport of *E. coli* to the shoreline and do not necessarily directly correlate to resulting water quality. For example, loads from a particular source for a specific day might be significantly different than the average daily loads due to factors such as weather. Loads from a particular source might also have a significant localized impact even though they are not a significant component of the total load. The impact of the sources will also be affected by lake conditions such as wave height, current direction, and boundary conditions (i.e., *E. coli* counts at the Illinois and Michigan state borders). Bacteria might also be surviving, or even multiplying, in beach sands or lake algae. These factors and others that affect resulting lake water quality conditions will be explored further during the modeling process.

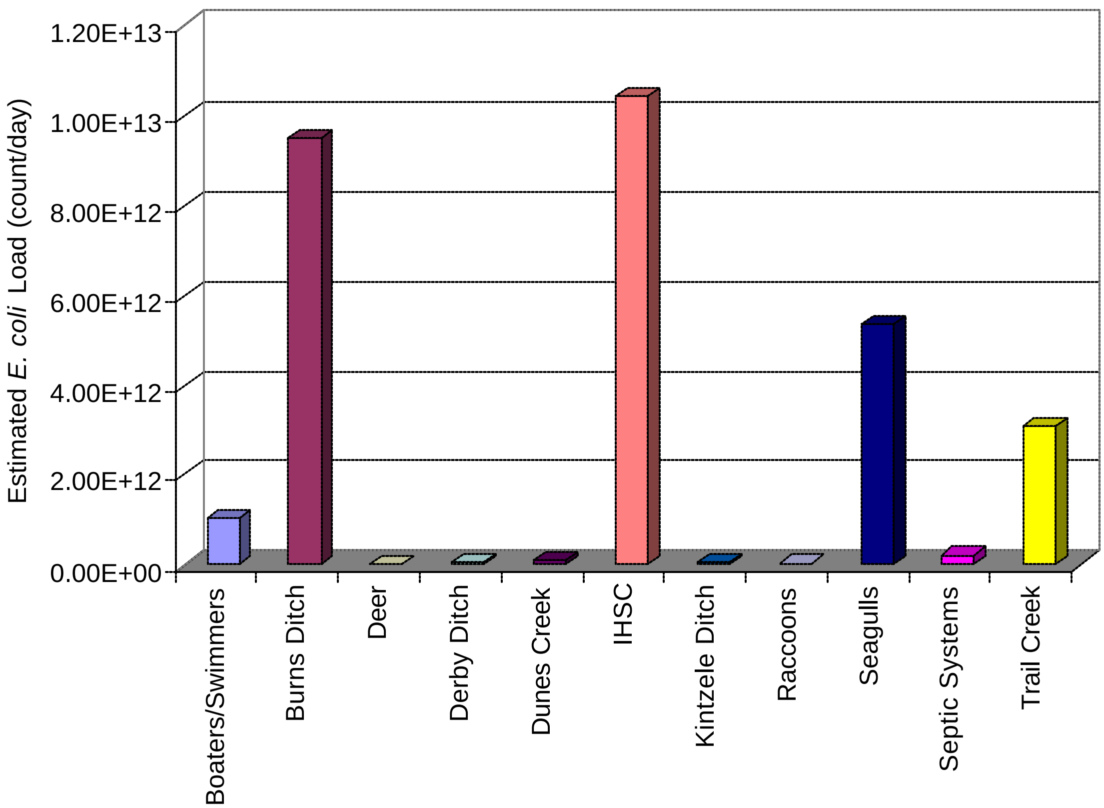


Figure 9. Summary of sources of *E. coli* to the Indiana portion of the Lake Michigan shoreline for the months April to October.

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